Ultra-Short-Wave Propagation: Mobile Urban Transmission Characteristics *

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This paper, a sequel to one entitled "Ultra-Short-Wave Propagation," deals with transmission in urban areas. The experimental data were obtained in the City of Boston on a frequency of 34.6 megacycles per second by means of a specially equipped motor car for carrying the receiver while the transmitter was fixed or vice versa.

Mass plots of these data show that the mean field strength varies inversely as the square of the path length which is the same variation as would be expected for level terrain in the absence of buildings. The same data are presented in the form of field strength contour maps.

These data are interpreted on the basis of the same physical picture which has been established for open country. The present data preclude interpretation upon the basis employed by earlier investigators of ultra-short-wave propagation through urban areas.

It is concluded that ultra-short-wave transmission in urban territory may be interpreted on the basis of transmission over level land plus the wave interference patterns caused by reflections from the buildings and an additional attenuation which on the average is independent of the length of the transmission path. Also, if the theoretical formula for the propagation of ultra-short waves over level terrain is used to calculate the received field in urban territory, and the height of the fixed antenna is measured from the local roof level instead of from the ground, these data indicate that the field strength so calculated would be near to the mean of the actual received field strengths in urban territory.

Introduction

THIS paper is a sequel to an earlier paper, "Ultra-Short-Wave Propagation,"[1] which dealt mainly with transmission across open country. In the present paper the research has been extended to include transmission within a built-up region. Additional problems of transmission within urban areas that result from man-made interferences, such as the noise produced by automobile ignition systems, have been investigated.

A specially equipped motor car was used as a mobile laboratory for most of this work both because of its convenience as a means of obtaining transmission data and because of the importance of mobile communication itself.

This paper describes general characteristics and quantitative measurements of the received signal on 34.6 megacycles. Transmission

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[1] J. C. Schelleng, C. R. Burrows and E. B. Ferrell, "Ultra-Short-Wave Propagation, *Proc. I. R. E.*, Vol. 21, pp. 427–463, March, 1933 and *Bell Sys. Tech. Jour.*, Vol. 12, pp. 125–161, April, 1933.

phenomena were studied in both directions between a fixed location on a building and the mobile laboratory.

Apparatus

Both terminals employed vertical half-wave antennas which were connected to balanced circuits by means of symmetrical two-wire transmission lines. At the fixed locations unloaded antennas were used; at the mobile terminal, in order to limit their heights to eight feet above the ground and maintain the symmetry the antennas were loaded so that their lengths were reduced to about a quarter of a wave-length (Fig. 1).

Fig. 1—Mobile receiving equipment.

The transmitter consisted of an electric oscillator employing two 75-watt tubes operating in push-pull relationship. At the fixed location, where ample power was available, the transmitter was capable of producing one ampere [2] of 100 per cent modulated carrier in its antenna without undue distortion. The mobile transmitter which used a dynamotor for tube plate supply was capable of producing the same current in its antenna. This corresponds to about six decibels less power due to the shorter antenna length.

The measuring set was of the double detection type with balanced high-frequency circuits, push-pull first detector and calibrated inter-

[2] The current was measured by a Weston type 425 thermoammeter at the current maximum.

mediate frequency attenuator.[3] This receiving equipment was calibrated in absolute units by a method described in the appendix. A mechanism for recording the field strength was attached to the measuring set: this consisted of a roll of paper that could be driven either by clock-work or by the rear wheels of the truck. The position of the recording pen was controlled by the setting of a manually operated variable attenuator. Samples of the type of record obtained are shown in Figs. 6 and 7.

Locations

The radiator for the fixed transmitter was supported by a fifty-foot pole above the roof of a seven-story building at the corner of Berkeley and Stuart Streets in the business section of Boston. The building is about 90 feet high, making the center of the antenna about 130 feet above the ground. Thus, the antenna was higher than most of the buildings of the city though it was lower than a few buildings nearby.

The antenna for the fixed receiver was supported by a 20-foot pole from the middle of the highest ridge of a gabled building making the center of the antenna about 80 feet above the street level. This building is located on the side of a slight slope in a fairly heavily wooded territory, on Seaverns Street near Center Street.

Field Strength Measurements

Transmitter at a Fixed Location

With a current of one ampere in the half-wave antenna[4] above the building at Berkeley and Stuart Streets and with the receiver in the truck, field strength measurements were made along various routes throughout Boston. These data have been averaged by one-tenth-mile intervals when the average radial distance was less than two miles and by half-mile intervals for greater average distances. A plot of these data is shown in Fig. 2. The points lie approximately on an inverse-square-of-distance line with deviations ranging up to about $\pm$ 10 db. An effort has been made to separate the points taken in the high building area. These points (shown as open circles) lie somewhat below the others with a few particularly low field strengths. The lowest field strengths of the business district were measured along the shore near Charles River Dam and near State Street on Atlantic Avenue. The field strengths in the business district would be expected to be lower because of the presence of the high buildings. The lower

[3] The set was similar to that described by Friis and Bruce, *Proc. I. R. E.*, Vol. 14, pp. 507–519, August, 1926.

[4] Since the antenna was in free space in so far as radiation resistance is concerned, this corresponds to a radiated power of 73 watts.

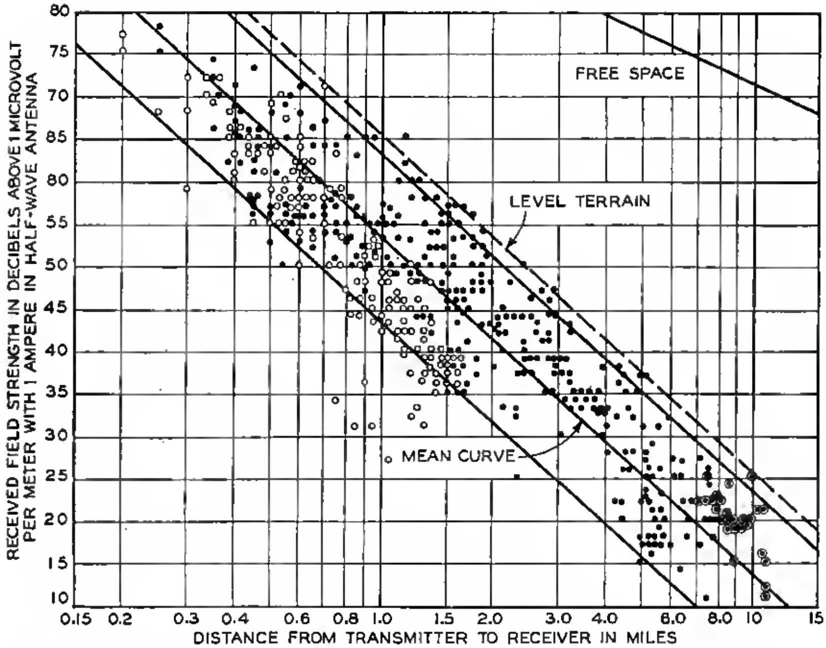

Fig. 2—Mass plot of field intensities measured at various distances from the transmitter at Berkeley and Stuart Streets in Boston. The values corresponding to distance less than two miles represent field strengths averaged over one-tenth mile intervals, while those for greater distances represent averages over one-half mile intervals. The open circles indicate fields in the high building area. Residential points outside the city limits have been enclosed in circles.

residential field strengths correspond to the region beyond Chestnut Hill.

When attempting to interpret the results of the mass plot of Fig. 2 a natural method would be to assume transmission as in free space plus an additional attenuation due to the proximity of the earth and obstacles above the earth's surface. The simpler case of transmission over level terrain in the absence of obstacles will be considered first.

It has been experimentally determined that the propagation of ultra-short waves over unobstructed paths follows the laws of optics [1, 5] so that the resultant field is composed of a well-defined reflected wave superposed upon a direct wave. Consequently for propagation over level terrain, the explanation is as follows (Fig. 3): Energy is propagated from a transmitter at A, at a height of h_1 above the ground, to a receiver at B, at a height of h_2 above the ground, both directly, as

[1] Loc. cit.

[5] C. B. Feldman, "The Optical Behavior of the Ground for Short Radio Waves," *Proc. I. R. E.*, Vol. 21, pp. 764–801, June, 1933.

represented by r_1, and by reflection at G, as represented by r_2, the distance between transmitter and receiver being represented by d. For the practical case where h_1 and h_2 are small compared with d the reflected wave impinges upon the ground at nearly grazing incidence, so that a negative reflection coefficient the magnitude of which is unity [6] for ordinary ground (not water) is obtained. This

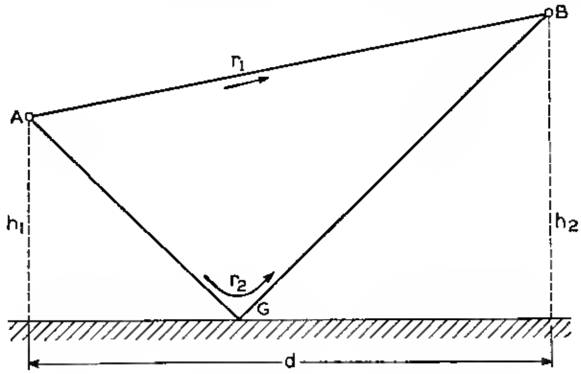

Fig. 3.

results in the field at B being the difference between two vectors of approximately equal magnitude and differing in phase by an amount corresponding to the difference in path lengths, r_2 and r_1. For the case under consideration,

$$r_2 - r_1 = 2h_1h_2/d, \tag{1}$$

and the angle between the vectors is

$$2\pi(r_2 - r_1)/\lambda = 4\pi h_1h_2/\lambda d. \tag{2}$$

[6] The magnitude is more exactly $1 - 2\epsilon(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for vertical polarization and $1 - 2(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for horizontal polarization, making the corresponding values for the received fields,

$$E_0\left(\frac{4\pi h_1h_2}{\lambda d}\right)\sqrt{1 + \frac{\epsilon^2(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)4\pi^2h_1^2h_2^2}} \tag{a}$$

and

$$E_0\left(\frac{4\pi h_1h_2}{\lambda d}\right)\sqrt{1 + \frac{(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)4\pi^2h_1^2h_2^2}} \tag{b}$$

respectively, instead of as in equation (3). When the lower of the two antennas is more than a couple of wave-lengths off the ground, the radicals are substantially unity. For the case under consideration it would be more accurate to refer to expression (*a*) as the theoretical formula but lack of knowledge of the magnitude of the dielectric constant and antenna heights that apply would introduce unnecessary uncertainty if the results were referred to this formula. It might be remarked that neglecting the presence of buildings and referring all heights to the local street level the radical represents an increase of 7–12 db for vertical polarization in the cases under consideration.

Except in the immediate proximity of the transmitter this angle is small and the resultant field is

$$E = E_0(4\pi h_1 h_2/\lambda d), \tag{3}$$

where E_0 is the free space field. Since [7]

$$E_0 = \frac{60\pi HI}{\lambda d}, \tag{4}$$

the resultant field becomes

$$E = 240\pi^2 HI h_1 h_2/\lambda^2 d^2. \tag{5}$$

Equation (5) shows that the field over level terrain is inversely proportional to the square of the distance from the source.[8]

Data presented in Fig. 8 of reference 1 show that at a frequency of 69 megacycles per second the field strength variation with distance follows approximately the inverse-square relationship for a range of from two to ninety kilometers.[9] In fact, the best straight line through these data agrees with the numerical values obtained from equation (5) well within the accuracy of the experimental data. Experiments designed to test the validity of this equation now are being conducted at Deal, New Jersey and data obtained to date confirm it both as to absolute value and variation with terminal heights and wave-length for horizontal polarization within the range $2 < h_1 < 25$, $2 < h_2 < 25$, $2 < \lambda < 17$, $d = 9{,}420$ and $26{,}300$, all measured in meters. The experimental confirmation of this formula for these distances indicates that the effect of the earth's curvature is secondary to the negative reflection effect upon which this formula is based. This might be expected in view of the fact that both diffraction and refraction tend to mitigate the additional attenuation that would be caused by reflection from a plane tangent to the earth's surface at the point of geometric reflection.

[7] If I is in amperes, d in meters, and H the effective height of the antenna, and λ the wave-length in the same units, E_0 is given in volts per meter.

[8] Since distance appears in this equation only as a factor and not as an exponent, the reduction with distance of the field strength of ultra-short waves over level terrain is independent of wave-length, polarization, dielectric constant, etc., as all of these quantities cancel in the ratio of the field strength at one point to that at another. The absolute magnitude of the field strength is proportional to the frequency for the same radiated power and antenna heights. If the antenna heights are sufficiently low, the field is also dependent upon the polarization and ground constants as indicated by expressions (*a*) and (*b*) of footnote 6.

[9] While undoubtedly at the greater distances the field suffers additional attenuation above that shown by equation (5) due to the curvature of the earth, such additional attenuation evidently takes place at distances beyond those employed in any of the authors' experiments.

When the propagation is through built-up areas instead of over level terrain the condition is more complicated. Even here, however, for terminals well above the tops of buildings, theoretical considerations [1] indicate that the same explanation of direct and reflected waves is valid. Data presented by Jones [10] may be used as a verification for this explanation even for transmission over buildings. Fig. 11 of his paper shows that for heights between 170 and 1,500 feet the field is proportional to the height in accordance with equation (5). When the terminals are lowered within the building region, the field should decrease more rapidly than proportionally with the height above the ground. In fact, data presented in Fig. 4 indicate that with one

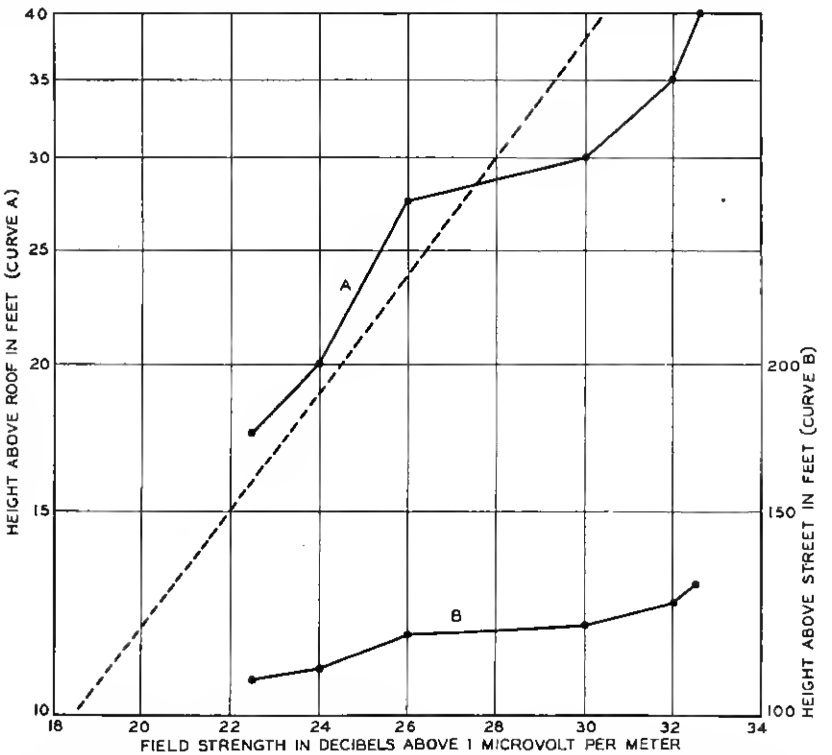

Fig. 4—Variation of field received at Berkeley and Stuart Streets with antenna height. Curve *A* shows the variation with height above the roof while Curve *B* shows the variation with height above the ground. The slope of the broken line indicates a linear relationship between field and height.

[1] Loc. cit.
[10] L. F. Jones, "A Study of the Propagation of Wave-lengths between Three and Eight Meters," *Proc. I. R. E.*, Vol. 21, pp. 439–486, March, 1933.

terminal above a flat roof that was approximately the same height as other nearby flat roofed buildings, the field strength is more nearly proportional to the height above the roof than to the height above the ground. When the terminals are lowered below the average building height additional complications are introduced. While this is somewhat difficult to picture because of the irregularity of the surface bounding the transmitting medium [11] the main outline seems simple enough. Above the building level there is a tendency for the field to follow the simple rules that hold for transmission over level country. In general the field strength actually received in the street would be proportional to the field strength overhead but of smaller amplitude since it is a product of scattering. This does not imply that the street signal comes down vertically; it probably is the result of scattering from points lying in a fairly large zone about the receiver and consists of a multiplicity of signals traveling in inclined directions.

Returning now to the present data on the propagation of ultra-short waves through urban areas, Fig. 2 shows [12] that the field strength is in general inversely proportional to the square of the distance from the transmitter. The mean curve through the data is 12 db below the curve for level terrain free from obstacles, plotted from equation (5) above, indicating the additional attenuation due to man-made structures. An analysis of the individual points shows that the reduction in field due to the obstacles (i.e., in addition to the level terrain attenuation) is independent of the distance so that there is no *absorption* due to the buildings in the usual meaning of the word; otherwise the additional attenuation would increase with the distance.

This method of interpretation is radically different from that of investigators of the propagation of ultra-short waves through urban areas whose papers have come to the attention of the authors.[13, 14, 15] They have assumed that the transmission occurs as in free space except for an additional attenuation *through the absorbing layer of buildings*. Such an assumption that the propagation of ultra-short waves is unaffected by the presence of the ground except in so far as the waves penetrate the absorbing layer of buildings, appears to be

[11] This surface is, of course, that formed by the ground and the walls and tops of buildings.

[12] It will be shown later that the empirical formula assumed by Schröter, Sohnemann, Jones, and Muyskens and Kraus cannot be made to fit these data.

[13] F. Schröter, "Zur Frage des Ultrakurzwellen-Runkfunks," *E. N. T.*, Vol. 8, pp. 431–436, October, 1931.

[14] K. Sohnemann, "Feldstarkemessungen im Ultrakurzwellengebiet," *E. N. T.*, Vol. 8, pp. 462–467, October, 1931.

[15] Henry Muyskens and John D. Kraus, "Some Characteristics of Ultra-High-Frequency Transmission," *Proc. I. R. E.*, Vol. 21, pp. 1302–1316, September, 1933.

inconsistent with the physical picture [1, 5, 16, 17] of ultra-short wave propagation which has been confirmed by basic experimental data.

Since the inverse-square-of-distance relationship (equation 5) which results from this physical picture is so different from the exponential relationship which results from the *absorption* assumption of previous investigators, the question arises as to the possibility of reinterpreting their data on the basis of this physical picture. The data presented by Muyskens and Kraus as Fig. 2 of reference 15 has been replotted in Fig. 5 of the present paper on logarithmic coordinates in order to

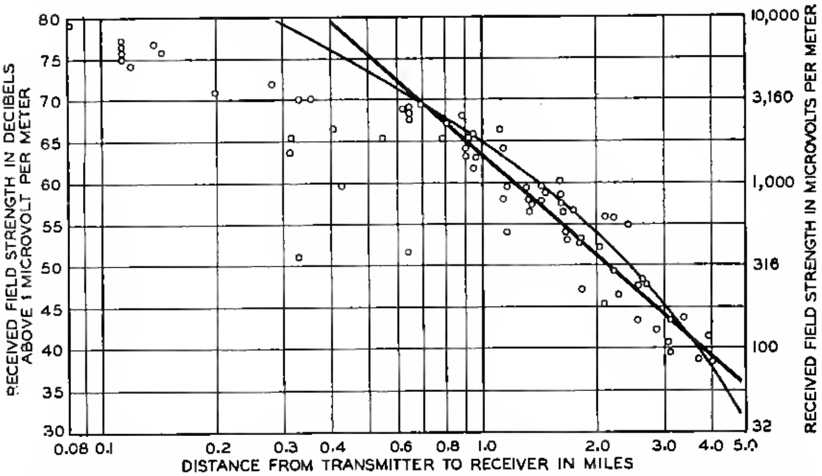

Fig. 5—Attenuation curve for 5 meter transmission as replotted from paper by Muyskens and Kraus, *Proc. I. R. E.*, Vol. 21, p. 1306, Sept., 1933. The straight heavy line shows an inverse-square of distance variation in accordance with the physical picture. The thin curved line is a replot of the curve presented by Muyskens and Kraus as representing these data by a variation according to an inverse-distance times an exponential factor. It is evident that these data may be interpreted equally well on the basis of the physical picture (heavy curve) as on the basis of the empirical equation assumed by Muyskens and Kraus.

facilitate reinterpretation on the basis of this physical picture. Figure 5 shows that it is possible to interpret their data as following an inverse-square-of-distance law equally as well as an inverse-distance law times an exponential factor.[18] In this interpretation little weight

[16] Bertram Trevor and P. S. Carter, "Notes on Propagation of Waves Below Ten Meters in Length," *Proc. I. R. E.*, Vol. 21, pp. 387–426, Mar., 1933.

[17] Carl R. Englund, Arthur B. Crawford and William W. Mumford, "Some Results of a Study of Ultra-Short-Wave Transmission Phenomena," *Proc. I. R. E.*, Vol. 21, pp. 464–492, March, 1933 and *Bell Sys. Tech. Jour.*, Vol. 12, pp. 197–227, April, 1933.

[18] Comparison of Figs. 2 and 5 on an absolute basis is difficult. The lower density of the buildings in Ann Arbor and the fact that the fixed antenna was located in as open a space as possible at the corner of the roof, combine to reduce the effect of the buildings in lowering the mean field strengths. Also the apparent absence of a measurement of the radiated power in the Ann Arbor experiments precludes the determination of the absolute value of the attenuation from the experimental data.

has been given to the points which are well below the curve, in accordance with the view of the experimenters that these points represent particularly unfavorable receiving locations.

Trevor and Carter [16] have made a similar interpretation of the data presented by Jones [10] which shows that for the larger distances the field strength was inversely proportional to the square of the distance. If this inverse-square-of-distance curve were extended to shorter distances it would be found that most of the nearby points would lie somewhat below it. This is presumably because of the lack of favorable receiving locations in the high-building area. While the empirical formula arrived at by Jones may represent his data satisfactorily, the physical picture assumed of a free space field times an absorption factor is untenable since it requires a radiated power approximately 20 db below that measured. Undoubtedly, the power radiated is not in error by this amount, since Trevor and Carter obtained a satisfactory numerical check on the basis of the other picture by using the value of power radiated as given by Jones.

It is possible, of course, to represent any data by an inverse-distance factor times an exponential factor for a limited range of distances. An attempt to do this with the data of Fig. 2 by making the empirical curve agree with the experimental inverse-square-of-distance curve at 1 and 4 miles results in a curve that agrees well with the data between 0.6 and 5.0 miles but is 11 and 22 db low at 0.2 and 12.0 miles, respectively. Even if these rather large discrepancies at the limits of the curve were neglected it would still be impossible to interpret the data in terms of the free space field times an exponential absorption factor, because of the fact that the empirical curve so determined requires a radiated power 35 db below that measured; this is untenable since the over-all uncertainty in the absolute value of the measurements is only a few decibels.

It should be pointed out that each point of Fig. 2 represents the average field over an interval of either a tenth or a half mile depending upon whether the transmission path involved was less or greater than two miles. Within each interval the field varied by five to fifteen decibels because of the local wave interference pattern, as is shown by the samples of the graphs taken with the recorder which are presented in Figs. 6 and 7. Fig. 6 is an example of the record taken in the business district of Boston at a distance of about one and a half miles from the transmitter near the region A shown in Fig. 8. The maxima and minima are spaced very closely and differ by ten to fifteen decibels. This was characteristic of the type of record obtained at the shorter distances. At the greater distances the magnitude of the local variations was less, as illustrated by Fig. 7, which is a sample of the record

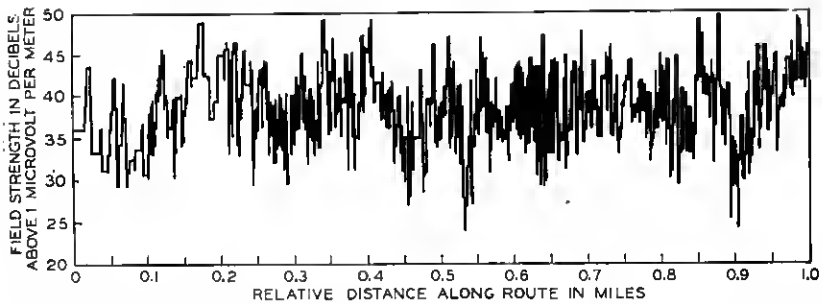

Fig. 6—Portion of record showing the large field strength variations as recorded while driving through the business district of Boston at a distance of about 1.5 miles from the transmitter.

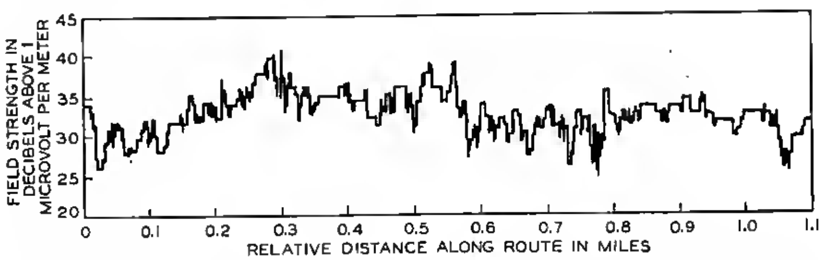

Fig. 7—Portion of record showing the small variations of field strength while driving through the residential section of Boston at a distance of about 5 miles from the transmitter.

taken at a distance of five miles (near B in Fig. 8). The change in the magnitude of the variations might have resulted from the fact that all of the data for the greater distances were taken in residential districts with correspondingly lower heights and densities of buildings.

An idea of the variations to be expected from the inverse-square-of-distance relationship is shown by the contour map of Fig. 8. The data already presented will give an idea of the impossibility of showing much detail in such a map. Likewise it would be an almost endless job to make measurements on every street in a city of this size. While data were obtained within reasonable intervals over the area for which solid contours are drawn (continuous field strength records taken over 143 miles of street are represented by this figure), another set of data might result in a somewhat different looking map. The broken contours are not based upon field strength measurements, but are merely a plausible way of joining the solid contours to aid the eye of the reader. The two 20 db contours in the lower part of the figure have not been joined because of insufficient data. The low field strengths along the Neponset River may be a result of local conditions and possibly the 20 db contours should be continued to the right along

an arc of more nearly constant radius. In this connection it may be mentioned that the field is nearly constant within the bulge of this contour to the southwest.

A striking fact brought out by the map is the crowding of the contours in the business district. There are particular directions for which the attenuation is greater presumably due to the combined effects of high buildings, for example to the east-northeast. There are other directions where the field strength is higher than the average. Several such places were noted when salt water extended immediately in front of the measurement location in the direction of the transmitter. The closed contours in the Mystic River to the north illustrate the better reception over salt water as predicted by theory.[1] An example of the records taken over bridges upon which these contours are based is shown in Fig. 9. (The route over which these data were taken is

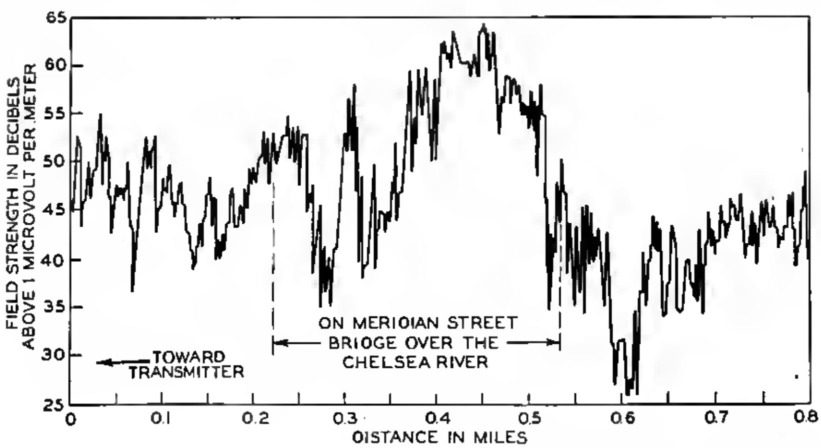

Fig. 9—Portion of records showing the variation of field strength on going over water.

indicated at C of Fig. 8.) The average increase in field when going over bridges was 10 db. This may be explained by the better conductivity of the water which results in a receiving directive characteristic that is more favorable to low angle reception. In some cases, the absence of buildings and increase in the height of the antenna due to the elevation of the bridge undoubtedly contributed to the greater field.

Another fact that is illustrated by the map is that the effects of obstacles and type of terrain are in general local. For example, the higher field strengths beyond salt water are soon reduced to normal with the intravention of additional land, illustrated at D in Fig. 8.

It was found that the field strengths along Columbus Avenue (indicated by E on Fig. 8) were about 10 db higher than those obtained on either side. This increase probably resulted from the fact that a

Fig. 8—Field strength contour map of Boston, Mass. Transmitter located at Berkeley and Stuart Streets as shown by the solid circle. Frequency = 34.6 mc. Field strength in decibels above one microvolt per meter with one ampere in a half wave antenna.

more or less unobstructed optical path existed along Columbus Avenue.

While a detailed analysis of the attenuation of ultra-short waves over paths as complicated as those considered in this paper is impossible, the known facts indicate several general characteristics that seem worthy of mention for further experimental investigation. The fact that the field was found to be approximately proportional to the height of the antenna above the roof level of the surrounding buildings (in Fig. 4), rather than to the height above the ground, as in the case of transmission over level terrain free from buildings, confirms the expectation that the "ground" conditions in the immediate vicinity of the fixed terminal would play an important part in determining the magnitude of the received field strength.

It is perhaps correct to assume that for the fixed terminal the height to be substituted in equation (5) should be the height above the roof rather than the height above ground. This would reduce the "level terrain" curve of Fig. 2 by 10 db.

Figures 6, 7 and 9 show marked wave interference patterns which indicate reflections from a multiplicity of points in the immediate vicinity of the mobile terminal. Besides these variations in the magnitudes of the fields observed at points in close proximity to each other, which are undoubtedly caused by reflections from irregularities in the immediate vicinity of the terminal, there are the variations represented by the spread of the points about the mean curve (Fig. 2). That these variations may be attributable to conditions local to the terminal is indicated by the fact that the increase in field on the far side of salt water and the decrease in the field on the far side of hills, etc., do not persist at further distances. Even if the irregularities of the contours of Fig. 8 were removed the contours would not be concentric circles about the transmitter. At this stage in the development it would be unwise to attempt to say how much of the deviation of the contours from circles may be attributable to directional characteristics at the fixed terminal and how much may be due to the intervening terrain. Statistically speaking, however, it is safe to say that the additional attenuation attributable to deviations from level terrain such as is produced by the presence of buildings, is independent of the length of the transmission path, so that there is no *absorption* in the usual meaning of the word. Another experimental result that points to the possibility that the effect of the buildings is local may be deduced from the data presented by Jones [10] and by Trevor and Carter.[16] The latter showed that the more distant points lie on the inverse-square-of-distance curve expected for transmission over level terrain free from buildings. The nearby points, however, lie below this curve, indicating that the major effect of the buildings is a local one.

The greatest difficulty encountered in attempting to apply the results of these experiments to the pre-determination of the field to be expected for transmission in other cities would be the interpretation of the method of assigning values to the heights in equation (5). While sufficient data are not available to establish an empirical relation, for a first estimation it seems reasonable that if the height of the fixed antenna were measured from the general roof level of the surrounding buildings and the height of the mobile antenna were measured from the street level, the resulting field strengths would lie within the range of expected values.[19]

Field Strength Measurements

Receiver at a Fixed Location

The field strength data obtained with the receiver at Seaverns Street and the transmitter in the truck are shown in Fig. 10. These

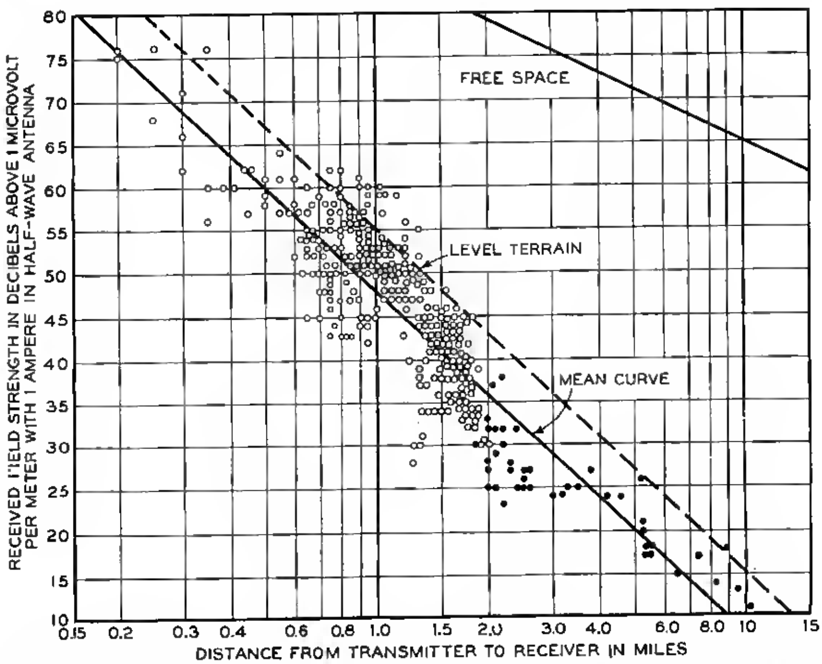

Fig. 10—Mass plot of field intensities measured with the transmitter at various distances about the Seaverns Street location. The open circles represent fields averaged over one-tenth mile intervals while the solid circles represent averages over one-half mile intervals.

[19] This should not be expected to be true for antennas close to the roof, since the field-strength obviously would not go to zero when the antenna height goes through the roof level. Extreme caution should be used in applying these results to cities in which the density and uniformity of buildings differ from those of Boston. When the topography departs greatly from that of level terrain, it would be difficult to infer the transmission conditions from the data here presented.

data may be represented also by an inverse-square-of-distance curve. By comparison with Fig. 2 no differences that can be attributed to the change in position of the fixed terminal nor the direction of transmission is evident. There is a small difference in the separation between the mean curves and the "level terrain" curves, but in both instances the mean curve lies very close to the level terrain curve (not shown) that would result from measuring the antenna height of the fixed terminal from the average roof level instead of from the ground.

Most of the nearby points were taken in the park system. They indicate that it is not more difficult to transmit through wooded areas than through built-up sections.

A field strength contour map illustrating the results obtained with the receiver fixed at Seaverns Street is shown in Fig. 11. The disturbing effect of hills is illustrated at several points on the map. There was a reduction of field when the transmitter was behind either Bussey Hill at *A* on the map or Green Hill at *B*, while the field was higher when the transmitter was between them. There was a rather deep minimum when the transmitter was immediately behind Parker Hill at *C* to the north, but half a mile farther away there was no noticeable effect.

Effect of Obstacles

In the course of the measurements some qualitative observations were made which will be summarized in this section. It was noticed in particular that when the receiver passed underneath an intersection of overhead trolley wires, the field was somewhat reduced. An example of this effect was observed at the intersection of Massachusetts and Huntington Avenues where the reduction was 15 db. At this point the maze of overhead trolley and support wires apparently constituted a fairly efficient screen for these waves. Observations made during the tests showed that sometimes the field was considerably reduced on the far side of hills as has been brought out by the contour maps. A large reduction in field strength resulted upon going behind a low hill on Saratoga Street on Breeds Island. The most striking example of this effect occurred with the measuring set at Seaverns Street and the mobile transmitter being driven from Huntington Avenue onto South Huntington Avenue (*C* of Fig. 11). Soon after rounding the corner at the foot of Parker Hill, which is 200 feet high, the average field dropped about 15 db.

The field was 20 db lower under Funeral Bridge than on either side of it. This is a stone and earth bridge appearing as a short tunnel to the road beneath it. The field was usually reduced upon passing underneath bridges of this general type of construction.

Fig. 11—Field strength contour map of Boston, Mass. Receiver located on Seaverns Street near Center Street as shown by the solid circle. Frequency = 34.6 mc. Field strength in decibels above one microvolt per meter.

A separation of the field strengths into those obtaining in the high-building area (indicated by open circles in Fig. 2) from those in the lower-building area (indicated by solid dots) shows that the attenuation is somewhat greater in the former.

No effect of the elevated railway structures on the average field was observed.

Noise Measurements

For reception in the car, by far the greatest interference is that caused by the electrical systems of passing automobiles. Special tests to determine whether or not street cars produced any noise gave a negative result. That is, under conditions where automobile noise was a limitation to reception, trolley noise was unaudible. While no special tests were made of the noise from elevated trains, at no time was it found objectionable.

With the receiver on top of the building at Berkeley and Stuart Streets, the predominating interfering noise was caused by an electrical substation next door. When the antenna was lowered approximately to the roof level the noise from the elevator motors and switching equipment in the pent house near by was well above any other noise. Upon raising the antenna to its proper position the elevator noise was reduced to a negligible amount compared with the power station noise, because of the combined effect of the directivity of the antenna and increased distance. The resulting noise was of approximately the same magnitude, indicating that the elevator switching noise was reduced by a fairly large factor in raising the antenna. This fact has an important bearing on reception of signals on the roofs of office buildings, since elevator switching noise is in general the limiting factor. Occasionally an automobile, started in the street below, would produce measurable interference. At Seaverns Street, however, the most objectionable noise was caused by the ignition systems of automobiles which were accelerating in low gear in the street below.

Acknowledgment

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APPENDIX

Methods of Calibrating

In order to obtain an absolute calibration of the measuring equipment, the field strength at a distant point in space, at the same height

above the ground as the center of the receiving antenna, was obtained by a standard method of field strength measurement.[20] This equipment then was removed and the truck placed in such a way that its antenna was always at the point where the field strength had been determined. By pivoting the truck about this point the horizontal polar diagram of the mobile receiving equipment was obtained. It is shown in Fig. 12. As the field was known at this point in the absence

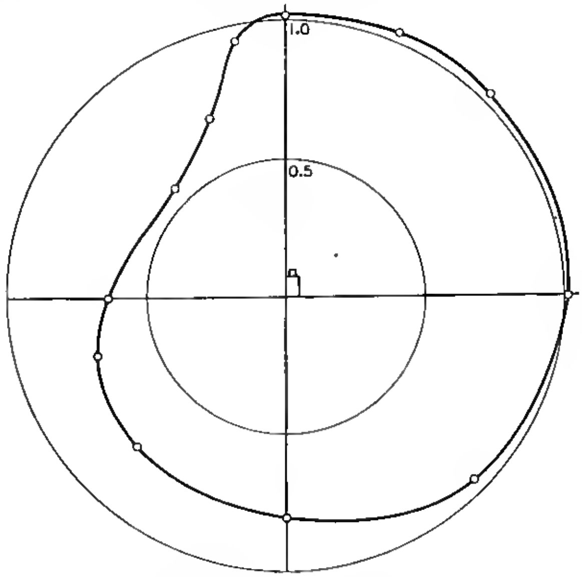

Fig. 12—Directional characteristic in the horizontal plane of the mobile receiver.

of the truck the attenuator settings gave a calibration of the receiving equipment for all directions. With this calibration as a standard, a comparison field generator which employed a loop radiator attached to the opposite side of the truck was calibrated also. The comparison field generator then was used throughout the test to check the calibration of the receiver. Since the polar diagram was fairly constant on the right side of the truck, care always was taken to orient the truck in such a way that the direction of the transmitter was at the right side rather than the left.

[20] This method consists of comparing the unknown field with a known field produced by a "Standard Field Generator," which is a small compact self-contained oscillator. It is very carefully shielded except for a small balanced loop extending in a vertical plane above the shield. A thermomilliammeter is located in the loop at the point of low potential with respect to the shield. From the reading of the meter and the dimensions of the loop, the field at nearby points may be computed. See *Proc. I. R. E.*, Vol. 21, pp. 430–431, March, 1933.

When the receiver was at Berkeley and Stuart Streets it was possible to employ the usual method of calibration [18] because the roof was flat. With the receiver at the Seaverns Street location, however, the gabled roof made it impractical to support the standard field generator opposite the midpoint of the antenna. In the latter case, accordingly, the constancy of the gain of the receiving equipment was depended upon in reducing the measurements to field strengths in absolute units. This lack of calibration did not introduce a large uncertainty, since the receiving equipment has been used over a period of years during which time its gain has remained constant within a few decibels.

Two-Way Tests

At the conclusion of this survey, actual two-way tests were made between a cruising car and fixed locations. For this purpose a car was equipped by E. B. Ferrell and R. C. Shaw [21] with an ultra-short-

Fig. 13—Fixed terminal transmitting equipment located at Berkeley Street.

wave transmitter and receiver arranged for simultaneous two-way communication. A distinctive feature of this equipment was the use of a single antenna for simultaneously transmitting and receiving. This was made possible by the use of a suppressor circuit in the receiver to prevent overloading of the first detector by the outgoing signal. With this suppressor circuit, which consisted of only a half

[21] Both of Bell Telephone Laboratories, Deal, New Jersey.

section of a simple band-elimination filter, it was possible to transmit and receive simultaneously on frequencies differing by only five percent.

The equipment at the fixed transmitting location is shown in Fig. 13.

The car was used for communication at distances up to about 5 miles from the fixed transmitter and up to a little over 3 miles from the fixed receiver. The circuit from the moving car to the fixed receiver was consistently good for distances up to about two miles.